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Error Patterns in Tactile Localization in Human Subjects

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Tactile localization error was studied on a selected forearm skin area of 4×4 cm in five human subjects. This test area was divided by grid lines at 4 mm intervals and a total of 121 cross points were obtained. Suprathreshold stimulus (8 g/0.5 mm^2) for eliciting tactile sensation was delivered to each cross point by means of a specially devised mechanostimulator. The subject was asked to respond immediately when he perceived the stimulus. The stimulus was then removed quickly and the subject was instructed to indicate the stimulated point without visual guidance, by touching the skin surface by himself using a hand-held stimulator given beforehand. The stimulated and indicated points were transcribed on a record sheet carrying a 121 point grid and they were connected by an arrow directed to the indicated point.

Thus the error of localization was estimated by the distance between the tested and indicated points, and by its direction, which was measured from the mediolateral line in degrees. The error magnitudes were distributed in the range from zero to 15.0 mm (mean 5.3-5.8, SD 2.6-3.1 mm) across subjects. About 70 % of the errors showed a preferred direction, either proximally or distally. About 25% of the errors had no preferred direction and half of them participated in making several foci (3 to 5) upon which arrow heads converged. The error magnitude became progressively greater as the stimulated points moved from the center of convergence. (Received June 28, 1983 and accepted July 18, 1983)

Key words: Tactile localization, Forearm skin, Human subject, Localization error

1 Introduction

Human subjects perceive the location of a tactile stimulus delivered to the skin surface with a certain degree of accuracy. This ability is called tactile localization and the distance between stimulated and perceived points provides a measure of the error of localization. This error was first examined by Weber[1] who demonstrated that it differed greatly over the various parts of the body surface.

Pritchard[2] further studied the nature of this localization function and observed that, after reduction of tactile sensibility by infiltration of a local anesthetic, the subject could no longer localize the stimulated point with the same accuracy as before. The importance of tactile sensation for the accuracy of tactile localization is obvious also from additional findings[3,4]. First, the error of localization was smallest where cutaneous touch spots were densely distributed in such skin surface as the finger tip. Second, the localization of a tactile stimulus was much more accurate than that of any other modality of stimulation such as pain, warmth or cold[5].

However, most studies concerning tactile localization aimed at elucidating the psychophysical capacity for spatial discrimination of the stimulated spot and little attention has been paid to the manner in which the error of localization is produced[6]. Since the accuracy of localization depends on both the intensity and the placement of the stimulus at different part of the body, we first attempted to understand how the perceptual threshold of a tactile stimulus is related to the error of localization.

To do this, we delivered a controlled tactile stimulus to a selected skin area of the forearm systematically and measured the perceptual threshold. The error of localization was characterized by its distance and direction. The assembled errors of localization suggest that there exist several modes of identifying the stimulated point. From these results, the neurophysiological basis of localization will be discussed. A preliminary report of these findings was published[7].

2 Methods

The experiments were performed on five healthy male volunteers including laboratory staff and medical students ranging in age from 19 to 32. The subject was asked to sit on a chair extending his left arm on a desk. To eliminate a sensory contribution from hair movement, the skin area to be tested was depilated carefully with microforceps. The room temperature was kept between 24 and 26°C and the humidity between 65 and 70%. The skin temperature was measured with a thermistor and was always in a range 34.0±0.5°C. The purpose of the experiments was briefly explained and the subjects were shown the experimental apparatus beforehand.

2・1 Controlled tactile stimulation

For controlling the intensity of cutaneous stimulation, we devised two kinds of mechanostimulators. The first, stimulator-H, was made of silver wire (0.5 mm dia.) coiled loosely around a smooth glass rod (10 mm dia.) : the other, stimulator L, was a stainless steel (0.2 mm dia.) coil enclosed in a glass tube (6 mm dia.). To the straight tips of the wires, small acrylic discs with diameter of 0.8 mm were cemented. Either glass rod or a glass tube served as the shaft of the stimulator mounted on a micromanipulator (Narishige SM-19). For calibration, the stimulator was vertically lowered at a constant speed of 1 mm/sec onto a digital analytical balance (Sartorius-2400). This speed corresponds to that employed for the localization test. the pressure applied per unit area of 0.5 mm^2 was estimated from the shortening of the coiled wire, which was read visually by an experimenter by means of a scale marked on the glass tube. This showed a quasi-linear relation in the range from 0 to 5 grams for stimulator-L and from 3 to 15 grams for stimulator-H (Fig. 1, left-hand graph). The calibration error was less than 5 % for each stimulator in the above range. Therefore, the tactile stimulation threshold was estimated from the calibration curve and was expressed by the pressure per unit area.

This test was performed over the palmer side of the mid-forearm region, which was easily accessible for the subject. For each subject a square area of 4×4 cm was drawn on the surface by two parallel lines distoproximally and mediolaterally. This skin area was divided by grid lines at 4 mm intervals and a total of 121 cross points were thus obtained. In 4 occasions, perceptual threshold was tested on a total of 441 points obtained by subdividing the skin area at 2 mm intervals. The procedure was as follows. A hand-held stimulator was given to the subject. The subject was asked to touch the skin surface with it and to focus his attention on the tactile sensation. After this training period, the subject was asked to keep his eyes closed and the test stimulus was applied to one of the cross points by lowering the micromanipulator vertically to the skin surface. Test stimuli were given in random order to each of the cross points and were occasionally given outside the square skin area so as to minimize artificial error due to the expectation that the stimuli should be delivered only within it.

The subject was asked to report immediately when he perceived the tactile stirmuli. The stimulus was then removed quickly and the subject was instructed to search for the stimulated point without visual guidance, by tuching the skin surface as using the stimulator given beforehand. In most instances, the subject could easily indicate a certain point as the stimulated one. Occasionally the subject could not indicate a point within 10 seconds after the stimulus, in which case the stimulus was repeated. To complete

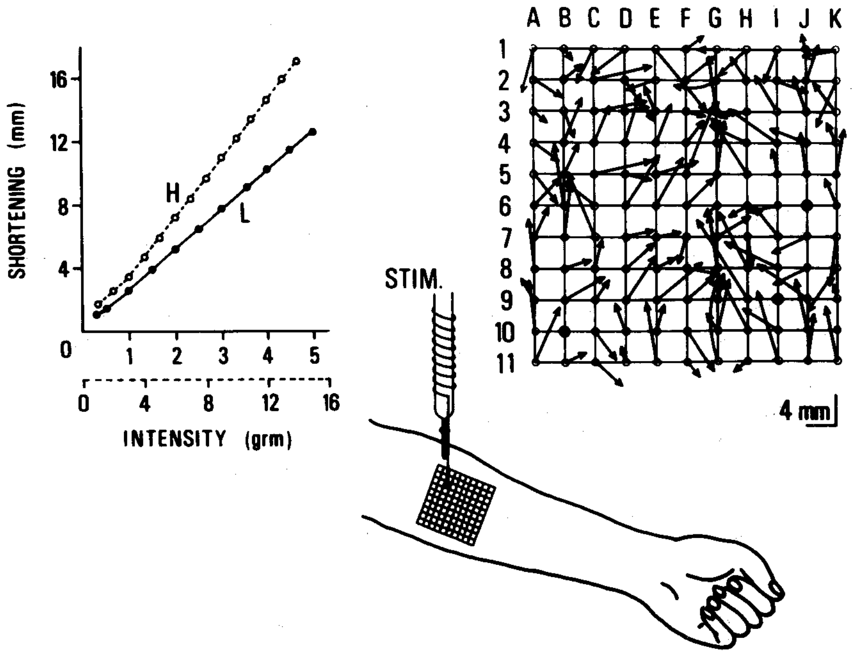

Fig. 1 A schematic illustration of the experiment. An inset graph to the upper left indicates the calibration curves for two mechanostimulators used (H and L). A diagram to the right shows an error distribution for subject YA. The arrows depict the magnitude and direction of the localization error. See text for details.

the stimulus sequence for all 121 cross points required about 3 hours.

Testing was accordingly divided into 3 to 5 sessions performed within one week.

2·2 Description of localization error

Similar grid lines as on the skin surface of forearm were transcribed on a record sheet, on which the stimulated and the indicated point were marked and connected by an arrow directed to the indicated one. Thus the error of localization was recorded in terms of magnitude and direction, which was measured from the mediolateral line in degrees. When the distance between the stimulated and indicated points was less than 1 mm, the error of localization was considered to be 0 (errorless) and was marked by a black circle. We summarized the error directions by plotting them on polar coordinate histograms and compared the distribution of them in each of four quadrnts. Error magnitudes were summarized in the form of simple histograms.

3 Results

3·1 Perceptual threshold and tactile stimulus intensity

As the first step of the present study, it was necessary to use a suprathreshold stimulus to provoke tactile sensation. For this, the relation between stimulus intensity and tactile sensation was analyzed on cross points along any one of the proximo-distal lines. Each point was stimulated twenty or more times at each intensity, which was systematically increased in steps. Percent correct detection was thus plotted against stimulus intensity. Fig. 2A illustrates the representative trials obtained from one subject. The sigmoid curves of percent correct detection reached maximun between 2 and 8 g/0.5 mm^2 of stimulus intensity. Across 4 subjects, errorless detection ranged from 1.0 to 8.0 g/0.5 mm^2 (Fig. 2B). These results

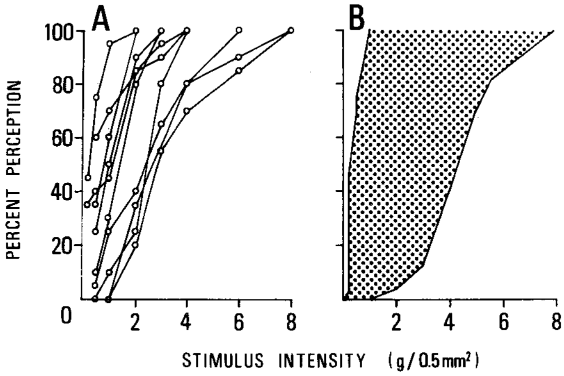

Fig. 2 Perceptual threshold and tactile stimulus intensity. A : results obtained from one subject on ten points. Percent perception was plotted against stimulus intensity measured as g/0.5 mm^2. B : the range of distributions of percent perception obtained from 4 subjects.

therefore justified using 8 g as the standard suprathreshold tactile stimulus for testing localization. At this intensity, tactile sensation was little if at all contaminated by pressure sensation.

3•2 Localization error and its distribution

Fig. 1 (right) summarizes the distribution of localization error in a tested area of one subject. During searching for the stimulated points, the subject was observed to touch the skin surface with stimulus intensities of 6 to 12 g. This observation also supported our previous notion that 8 g of controlled stimulus intensity provoked predominantly tactile sensation for the subject. Out of 121 tested points, only 3 points (B, 10 : I, 9 ; J, 6) were identified without error. At other points, the error magnitude was as high as 15 mm. To further study in detail the properties of error distribution, we have compared the results obtained from 5 complete sets of stimulus presentation in a single subject. Since the error distributions showed a similar pattern across sets of trials, two representative examples are illustrated in Fig. 3.

In this figure, error magnitudes are shown in the form of a simple histogram and direction errrors as a polar coordinate histogram. Comparison of these results shows that the error at each point was not identical across each of the trials. However, the error magnitudes were distributed in a similar range from 0 to 12 mm and had identical means and standard deviation, There was no significant difference across the 5 sets of presentations (one-tailed analysis of variance, $p<0.05$). Similar analysis performed on 5 subjects also demonstrated that there was no significant difference across subjects ($p<0.05$). This result is summarized in Table 1.

The error directions in subject YA showed that about 70 % of scores were distributed in the first and the second quadrants of a polar coordinate graph all through these trials (Fig. 3). This indicated that in this subject the stimulated points tended to be mislocated proximal to the point stimulated. In addition, careful observation of the ensemble of arrows in Fig. 3 suggested that there were several foci (B, 5 ; G, 3 and G, 8) upon which arrow heads converged. This suggestion of foci was reinforced by the results of repeated trials on subject YA. We have arbitrarily defined such a focus as the center of a circle of 4 mm dia, that enclosed 5 or more arrow heads. In all five sets of presentations on YA, such foci were found at B, 5 ; G, 3 and G, 8, although the arrows did not always originate from the identical stimulation points in each trial. These foci suggest that there are scattered foci where there is an increased probability of perceived

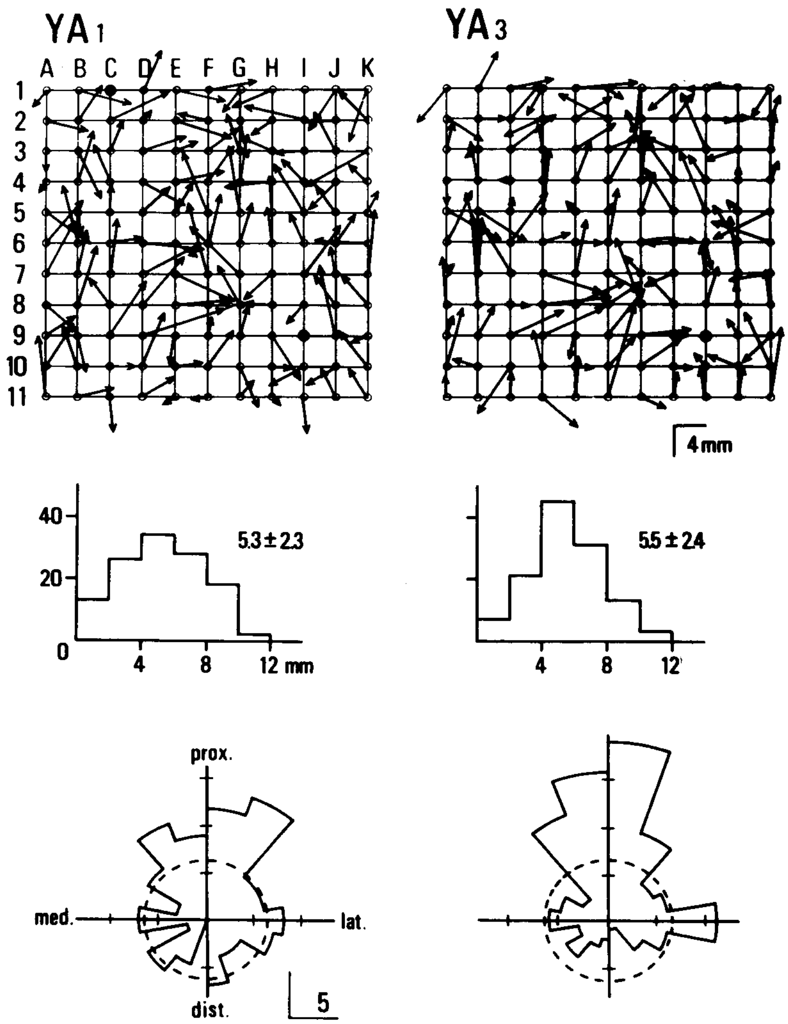

Fig. 3 Variation of localization error across trials. Upper set-error distributions, middle set-histograms of the localization error magnitude with $\bar{X}\pm SD$, lower set-polar coordinate histograms of the error directions of lst, 3rd trial respectively in subject YA.

Table 1 *Variation of the magnitude of localization error across 5 subjects.*

Subject	MIN.	MAX.	MEAN	SD (mm)
MA	0	12.8	5.3	2.6
KO	0	13.2	5.5	2.9
TY	0	14.4	5.6	3.0
YA	0	11.8	5.5	2.4
SK	0	15.0	5.8	3.1

localization of tactile stimuli.

To examine whether such foci existed in our other subjects, we made a similar analysis of error distribution, as shown in Fig. 4. In each subject, from 3 to 5 points were identified without errors and similar error magnitude histograms were obtained. In contrast to subject YA the error direction was consistently distal in these subjects. Convergent foci were observed at the regions A, between 5 and 6 ; D, 8 and between D and E, 3 for subject MA and the regions between A and B, 7 ; between B and C, 2 ; C, 5 and G, 6 for subject KO. There was no consistent spatial relationships between these foci and the points without errors.

In every subject, about 70 % of the arrows showing error distribution had a preferred direction, either proximally (Fig. 3) or distally (Fig. 4) and thus formed a stream. About 25 % of the arrows appeared to have no preferred direction and half of them participated in making several convergent foci. The residual 3 to 4 % of the stimulated points were identified without error. We did not observe any subject whose error distribution showed a lateral preference.

To facilitate the comparison of the arrow directions which did or did not participate in forming the

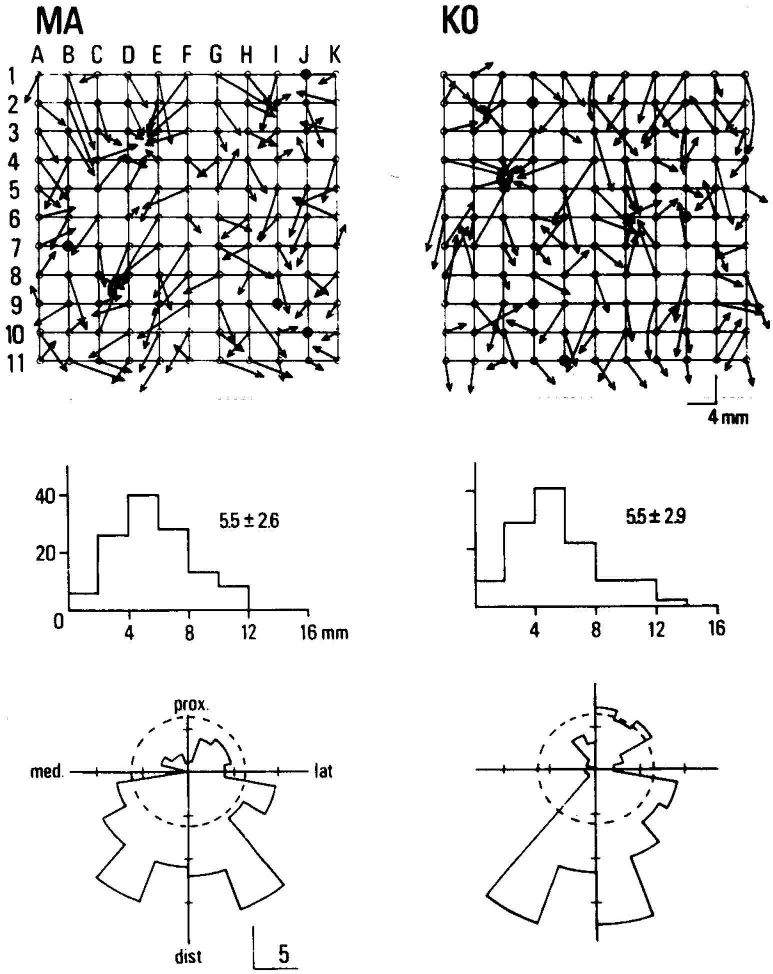

Fig. 4 Variation of localization errror across subjects. The results from subject MA and KO are shown. Format as in Fig. 3.

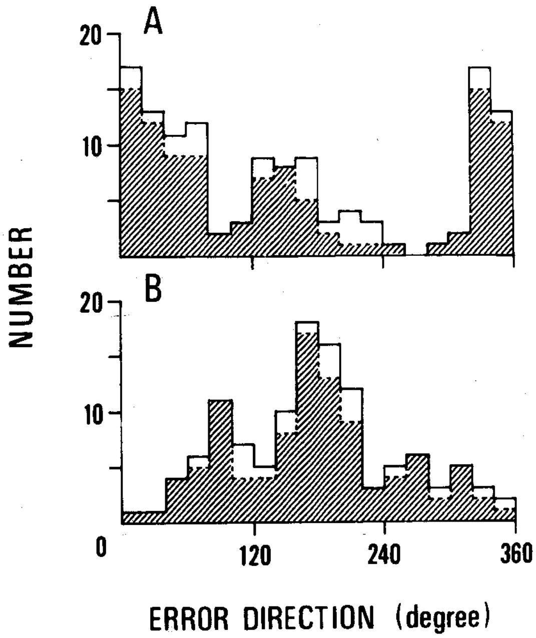

Fig. 5 Histograms of the distributions of arrow angles, in which lateral to medial direction of the grid line served as 0–180 degrees directional perference to the proximal direction for subject (A) and distal direction (B) is shown. Shaded and unshaded portions of histograms indicate distributions of non converging and converging arrows respectively. See text for details.

convergent foci, we plotted each arrow angle from 0 to 360 in a form of distribution histogram. Fig. 5 represents the distributions of angles obtained from two subjects showing proximal (A) and distal (B) directional preferences. In each figure, the histogram with solid lines represents the distribution of all 121 angles of the arrows and that with broken lines represents that of arrows not participating in convergent foci. Accordingly, unshaded portions of the histogram indicates the distribution of arrows participating in forming the foci. From these results, it became clear that the convergent foci were formed by arrows distributed in all directions.

3・3 Convergence of arrows and its characteristics

Convergence of arrows was observed consistently across subjects and the number of the foci was usually 3 to 5. As a next step, a center (0) of convergence was marked and the neaby skin surface was systematically stimulated to examine how such convergence was formed. To do this, we stimulated points every 2 mm along 4 lines from the center as shown in Fig. 6. More than 10 stimulus presentations were made at each point in a random sequence and each of the localization errors was superimposed on the stimulated point.

Fig. 6 summarizes these superimpositions obtained from 7 points along the center to distal lines. The perceptual threshold of these 7 points were distributed in the range from 0.29 to 2.0 g. They were not orderly located from the lower to the higher values in proportion to an increase in the distance from the

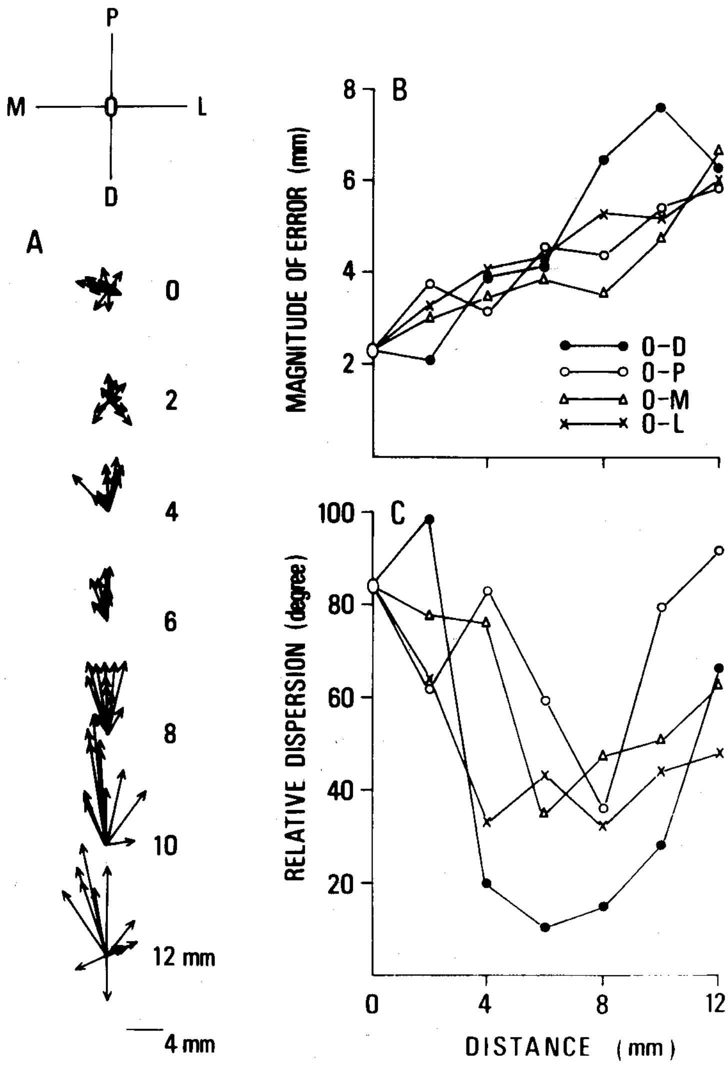

Fig. 6 Localization errors in the area around a focus of convergence. Localizations were examined at 2 mm intervals along rectangular coordinate axes as shown in the upper left. A: an example along the O-D line. The numbers to the right indicate the distance of stimulated point from (O). B: mean arrow magnitudes as a function of the distance from (O) tested along each of 4 lines. C: relative dispersion represents 1 SD of error directions.

center (0). The mean error magnitude became greater as the stimulated point moved distally from the center as shown in Fig. 6. However, the coefficients of variation of the error magnitude at each point did not differ at each stimulated point and remained at the some value of 20 to 30 %. There were no systematic relations between the difference in the perceptual threshold and that in the coefficient of variation.

Fig. 6C represents how the preferred error direction changes in relation to the distance from the center (0). We plotted relative dispersion of arrow angles against the distance. Near and at the center (0)

, arrow heads were directed to all the directions. At a distance of 6 mm, however, most arrows were directed to the center and the degree of relative dispersion became smallest. As the stimulated point moved further distally, the preferred direction was again gradually lost. In all the 4 lines tested, the minimum dispersion of arrow heads was observed at the distance from 4 to 8 mm from the center (0). This result suggests that the tactile stimuli delivered not at the center but at a point which is located about 4 to 8 mm distally from the center could produce preferred error directions which are important for forming the convergent foci.

3•4 Paired tactile stimuli and perceptual location

To analyze further how this particular mode of error direction is concerned with the discrimination of stimulated points, we presented pairs of tactile stimuli in various temporal and spatial combinations. We delivered two stirmuli sequentially, one to the center of convergence (0) and the other to the regiton encircled with a radius of 6 mm from 0 and examined whether they were perceived as different points by the subject. If the center of convergence was stimulated first (a few seconds prior to the other point), they were always perceived as the same point but as a different point when the sequence of the stimuli was reversed. When the two different sites within the radius of 6 mm, but neither on 0, were stimulated, the subject reported that each stimulus was applied to the same point, but different from point 0, irrespective of the sequence of the stimuli. However, paired stimuli delivered within a few seconds successively, one within and the other beyond the radius of 6 mm, were always perceived by the subject at two different stimulated sites.

4 Discussion

Extensive studies have been made in an attempt to understand the functional meaning of localization errors[3,4]. To do this, various methods with or without visual cues have been employed[8,9]. These studies were aimed at elucidating the capacity of human subjects for spatial discrimination of the stimulated spots over the different regions of the body surface. In the present study, we have attempted to understand the neurophysiological basis of tactile localization with an assumption that the localization errors reflect the neural events in the process of tactile perception.This process would involve several sequential stages of neural activities. First, a test stimulus delivered to the subject by the experimenter would provoke tactile sensation. Second, the subject would keep his image or memory of the stimulated point. Third, the subject would move his arm and hand to explore his skin surface repeatedly until he identifies a certain point, stimulation of which provoke tactile sensation matching the image or memory of the test stimulus.

Firstly, it appears certain that tactile sensation is the exclusive cue for localization in this experiment. The subject could not indicate the stimulated point when the test stimulus did not provoke clear tactile sensation. Also it was confirmed from the following experiments that no systematic errors in magnitude and direction occurred without tactile cue. When the subject looked at a similar grid as that on the forearm on a table, a mark was made on the grid by the experimenter and the subject was asked to indicate the marked position after his eyes closed. Although the subject could indicate its position, the error magnitude was larger and neither direction preference nor arrow convergence was observed on repeated trials.

Involvement of the tactile system such as cortical sensory area and parietal cortex in tactile discrimination in space and identification of the test stimulus is known in man and animals[10,12]. Clinically, errors of reference, particularly proximal ones are known in individuals with lesion of the parietal lobe or in aged people[13,14]. This fact may imply that parietal cortex plays an important role in producing the preferred error direction, either proximal or distal in this study.

Exploration of the stimulated point, which may be regarded as a kind of movements in intrapersonal space (movements executed with the body as reference), is considered to involve the motor and supplementary areas in the programming and execution of movements. Recent study[15] in man has revealed that activities of the contralateral and both supplementary areas, and in some degree premotor and sensory areas, increase significantly during executing a few types of learned voluntary movements in intrapersonal space.

Another important feature of tactile localization was convergence of arrow heads. About 25 % of the arrows participated in forming several foci upon which arrows had converged. Since the error magnitude was minimum near the center of focus and paired stimuli delivered within the encircled area with a radius of 6 mm tended to produce the same tactile sensation, afferent inputs from this area may have activated the same functional group of cortical neurons[11]. These neurons may be more strongly involved in determining the matching between the image of the test stimulus and the tactile stimulus during searching for the stimulus point. The tactile inputs from this focus and the surround may converge on these neurons, resulting in indicating this focus.

Thus, systematic distribution of localization errors strongly suggested that there exist some neural arrangements underlying tactile localization function common to all the subjects tested. However, it appears premature at present to relate our results directly with any of the available neurophysiological findings such as peripheral receptive field organizations[16-19] and afferent impulses in cutaneous nerves[20-24].

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References

1. Weber, E. H.: Ueber den Raumsinn und die Empfindung Kreise in der Haut und in Auge. Ber. sachs. Ges. Wiss. Math-phys. cl. 85-164 (1852).
2. Pritchard, E. A. B.: Cutaneous tactile localization. Brain **54**, 350-371 (1931).
3. Davson, H. and Eggleton, M. G.: Principles of Human Physiology, 14th ed., 1424-1453 Churchill, London (1968).
4. Sinclair, D.: Cutaneous Sensation. Oxford Univ. Press, London 1-306 (1967).
5. Nathan, P. W. and Rice, R. C.: The localization of warm stimuli. Neurology (Manneap.) **16**, 533-540 (1966).
6. Mountcastle, V. B. and Powell, T. P. S.: Neural mechanisms subserving cutaneous sensibility with special reference to the role of afferent inhibition in sensory perception and discrimination. Bull. Johns Hopkins Hosp. **105**, 201-232 (1959).
7. Yamamura, T., Aoki, M. and Mori, S.: Percepting manner of the site of tactile stimulation in man. J. Physiol. Soc. Jpn. **38**, 139 (1976).
8. Boring, E. G.: Sensation and perception. In: The History of Experimental Psychology, 644-654 Appleton-Century-Crofts, New York (1942).
9. Head, H. and Holmes, G.: Sensory disturbance from cerebral lesions. Brain **34**, 102-254 (1912).
10. Johnson, D., Jürgens, R., Kongehl, G., and Kornhuber, H. H.: Somatosensory evoked potentials and magnitude of perception. Exp. Brain Res. **22**, 331-334 (1975).
11. Mountcastle, V. B.: Neural mechanisms in somesthesia. In: Medical physiology, 13th ed., 307-347, Mosby, Saint Louis (1974).
12. Nakanishi, T., Takita, K., and Toyokura, Y.: Somatosensory evoked responses to tactile tap in man. Electroenceph. Clin. Neurophysiol. **34**, 1-6 (1973).
13. Bender, M. B.: Disorders in Perception, with particular reference to the phenomena of extinction and displacement. 1-109, Charles C. Thomas. Springfield (1952).
14. Critchley, M.: The parietal lobes. 1-156 Edward Arnold Co. London (1953).
15. Roland, P. E., Larsen, B., Lassen, N. A., and Skinhoj, E.: Supplementary motor area and other cortical areas in organization of voluntary movements in man. J. Neurophysiol. **43**, 118-136 (1980).
16. Aoki, M. and Yamamura, T.: Functional properties of peripheral sensory units in hairy skin of a

cat's forelimb. Jpn. J. Physiol. **27,** 279-289 (1977).
17. Bishop, G. H.: Responses to electrical stimulation of single sensory units of skin. J. Neurophysiol. **6,** 361-382 (1943).
18. Burgess, P. R., Howe, J. F., Lessler, M. J., and Whitehorn, D.: Cutaneous receptors supplied by myelinated fibers in the cat. II Number of mechanoreceptors excited by a local stimulus. J. Neurophysiol. **37,** 1373-1386 (1974).
19. Miller, M. R., Ralston, H. J., and Kasahara, M.: The pattern of cutaneous innervation of the human hand. Amer. J. Anat. **102,** 183-217 (1958).
20. Aoki, M.: Somatotopic organization of the cuneate nucleus in the cat, with special reference to forepaw cutaneous projections. In: R. Porter (ed.). Studies in Neurophysiology, 253-266 Cambridge Univ. Cambridge (1978).
21. Hensel, H. and Boman, K. K. A.: Afferent impulses in cutaneous sensory nerves in human subjects. J. Neurophysiol. **23,** 564-578 (1960).
22. Knibestöl, M. and Vallbo, A. B.: Single unit analysis of mechanoreceptor activity from the human glabrous skin. Acta Physiol. Scand. **80,** 178-195 (1970).
23. Aoki, M.: Afferent inhibition on various types of cat's cuneate neurons induced by dynamic and steady tactile stimuli. Brain Res. **221,** 257-269 (1981).
24. Vallbo, A. B. and Hagbarth, K. E.: Activity from skin mechanoreceptors recorded percutaneously in awake human subjects. Exp. Neurol. **21,** 270-289 (1968).

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ヒト触覚局在能の誤差パターン

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ヒトの触覚の局在能について，従来報告されていない興味ある知見を得た．

５人の正常被検者について，前腕の皮膚面上の領域（４cm×４cm)を選び，触覚の局在能の誤差について調べた．この領域内にさらに４mm 間隔で縦横に格子線を引く事により合計121点の交点が得られた．この各交点を検者が触刺激装置を用いて順次に閾上刺激（８ g/0.5mm²)を加えて触覚を生じさせた．被検者は閉眼のまま触刺激を知覚すると，他方の手に持った別の触刺激装置で刺激点を指示した．ほとんどの場合，刺激点と被検者の指示点とは一致せず，通常数 mm 程度の誤差を生じた．この前腕皮膚面上の領域をグラフ紙上に数倍に拡大した図上で刺激点と指示点とを線で結び，また刺激点から指示点に向かう矢印により方角を表して記録した．

局在能の誤差は刺激点と指示点とのずれの距離(mm)と方角すなわち，前腕内外側方向の線となす角度を測定して定量化した．誤差の大きさは，５人について 5～15 mm（平均5.3～5.8 mm 標準偏差2.6～3.1mm)に分布していた．誤差の方角については，約70%のものが腕の中枢側か又は末梢側を指示する方角性を持っていた．25%のものは矢印の先が数か所（３～５）に収束して「焦点」を形成した．誤差の大きさは刺激点がこの矢印の収束部の中心から離れるにつれ増大する事がわかった．